E98

High Speed Two Phase 2a (West Midlands - Crewe)

Background Information and Data

CA1: Fradley to Colton

Hydraulic modelling report - River Trent and Bourne Brook

(BID-WR-004-002)

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1 Introduction

1.1 Background

1.1.1 This document presents the results of the hydraulic modelling carried out in the Fradley to Colton area (CA1) relevant to High Speed Rail (West Midlands - Crewe). The following hydraulic modelling reports are also relevant to the Fradley to Colton area:

- Hydraulic modelling report - Pyford Brook (Volume 5: Background Information and Data 004: BID-WR-004-001);
- Hydraulic modelling report - Moreton Brook (Volume 5: Background Information and Data 004: BID-WR-004-003); and
- Hydraulic modelling report – Stockwell Heath (Background Information and Data 004: BID-WR-004-004).

1.1.2 The water resources and flood risk assessment is detailed in the High Speed Rail (West Midlands - Crewe) Environmental Statement (ES)[1]. Volumes 2, 3 and 4 discuss water resource and flood risk effects and Volume 5, Appendices sets out the following relevant to the Fradley to Colton area:

- a route-wide Water Framework Directive compliance assessment (Volume 5: Appendix WR-001-000);
- a water resources assessment (Volume 5: WR-002-001);
- a flood risk assessment (Volume 5: WR-003-001); and
- a route-wide draft water resources and flood risk operation and maintenance plan (Volume 5: Appendix WR-005-000).

1.2 Aims

1.2.1 The Proposed Scheme includes a number of locations where the route will cross watercourses and their floodplains. The Proposed Scheme crossing locations have the potential to increase flood risk where they restrict flood flows or change floodplain dynamics.

1.2.2 At the locations detailed in this report, the route will cross Bourne Brook on the proposed Kings Bromley viaduct; as well as the River Trent, Crawley Brook, Luth Burn and a number of unnamed watercourses on the proposed River Trent viaduct.

1.2.3 A hydraulic model of Bourne Brook, Crawley Brook, Luth Burn and the River Trent was created to simulate the risk of flooding in this location for an approximate 18km stretch of the River Trent and an approximate 5km stretch of Bourne Brook. This report documents the methods used and discusses the results, assumptions and limitations imposed by them.

[1] HS2 Ltd (2017), *High Speed Rail (West Midlands - Crewe) Environmental Statement (ES)*, www.gov.uk/hs2

1.2.4 Hydraulic models of the existing conditions and with the Proposed Scheme included have been evaluated to assess the impact of the Proposed Scheme on flood risk and to derive peak flood water levels relative to the proposed structures.

1.2.5 This report details the existing hydrological and hydraulic processes of the reaches modelled and how these will be affected by the Proposed Scheme.

1.3 Objectives

1.3.1 The objectives were to:

- conduct, where feasible, a site visit to inform understanding of existing conditions, including existing channel and floodplain characteristics, hydraulic structures and flow paths;
- estimate flow hydrographs at the Proposed Scheme crossing location;
- develop a hydraulic model, commensurate with the level of detail required and available at this stage, to provide peak levels at key structures for the Proposed Scheme, based on the most suitable data available and flow hydrographs developed; and
- analyse the impact of the Proposed Scheme on flood risk levels obtained from the results of the following Annual Exceedance Probabilities (AEP): 50%, 20%, 5.0%, 1.33%, 1.0%, 1.0%+climate change (CC), 0.5% and 0.1%.

1.4 Justification of approach

1.4.1 The hydraulic model has been constructed to provide an awareness of existing flood risk to inform the Proposed Scheme design. The detail included identifies potential impacts of the Proposed Scheme on surrounding land and to ensure that 0.6m freeboard to soffit is provided in a 1.0%+CC AEP event and 1.0m freeboard to track level is provided in a 0.1%AEP event.

1.4.2 A 1D-2D linked hydrodynamic model approach was selected for this study because this method is particularly suited to the inclusion of complex pathways within the floodplain as well as allowing the channel and floodplain interactions and flow dynamics to be represented.

1.4.3 An existing 1D model containing cross-sectional survey data was provided by the Environment Agency for the River Trent. The floodplain element was originally modelled in 1D only, and combining this with a new 2D model domain provides an improved representation of the floodplain.

1.4.4 Due to the Proposed Scheme crossing the floodplain on a viaduct, and thus causing a high level of risk for the design of the project and its impact on the environment, it was proposed that hydrological calculations be undertaken to a full level of detail. This considered Flood Estimation Handbook (FEH) Statistical, Revitalised Flood Hydrograph 2 (ReFH2) and the hybrid methods. This is particularly relevant in this location where both abutments are driven by flood risk.

1.5 Scope

1.5.1 The scope of the study is to undertake hydraulic modelling to enable an assessment to be made of the impact of the Proposed Scheme on the local environment. The models should be detailed enough to allow future assessment of different options associated with each crossing location, to allow the management of flood risk and correct sizing of crossing openings.

1.5.2 The report focuses upon:

- discussion of all relevant datasets, quality and gaps;
- hydrological analysis undertaken, approach used and calculation steps;
- integration of the hydrological analysis with the hydraulic modelling;
- hydraulic modelling methodology chosen, with clear identification of general methodologies and justification; and
- hydraulic modelling parameters, assumptions, limitations and uncertainty.

2 Site characteristics

2.1 Description of the study area

Model reach

2.1.1 The section of the River Trent being modelled is located approximately between Rugeley Power Station significantly upstream of the Proposed Scheme crossing and Wychnor Hall Farm. Figure 1 shows the modelled extent, with the model upstream boundary located approximately 550m downstream of Colton Mill Bridge. The downstream boundary is located approximately 450m south-west of Wychnor Hall Farm and approximately 1.6km downstream of the Trent and Bourne Brook confluence. Bourne Brook is incorporated from downstream of Kings Bromley Marina to its confluence with the River Trent. Approximately 16km of the River Trent and 1.75km of Bourne Brook has been modelled.

2.1.2 The River Swarbourn from Yoxall village to 2km upstream of its confluence with the River Trent and the River Blithe from Hamstall Ridware Bridge to its confluence with the Trent have also been included. Luth Burn is included along a 300m stretch beneath the north abutment of the proposed River Trent viaduct.

2.1.3 Within the study area there is one major settlement, the village of Kings Bromley. There are a number of isolated properties in addition to this, particularly along Shaw Lane. Transport infrastructure in this area is prominent with two A-roads. One of which, the A515 Lichfield Road, crosses the River Trent floodplain between Yoxall and Kings Bromley on an elevated causeway. The A513 Rugeley Road crosses the floodplain at approximately ground level to the south-west of Kings Bromley. The West Coast Main Line (WCML) crosses the floodplain near the models' upstream extent shortly before Rugeley Trent Valley Railway Station.

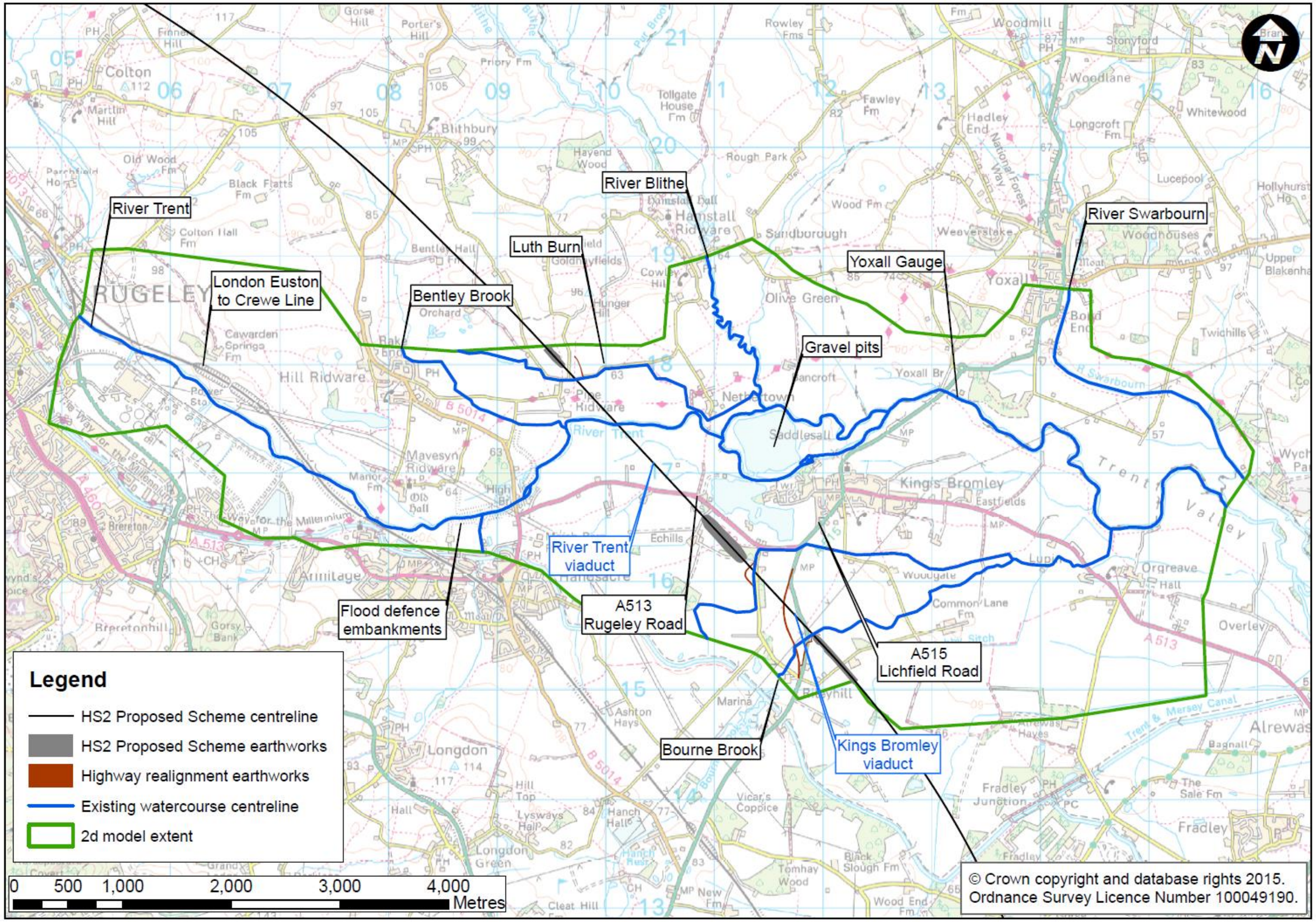
2.1.4 There are a number of crossings of the River Trent along the study reach, including the B5014 Ridware Road near Handsacre, the WCML near Rugeley and the A515 Lichfield Road near Yoxall. There are two older disused highway bridges immediately adjacent to the existing bridges, at the B5014 Ridware Road and A515 Lichfield Road crossings. The A515 Lichfield Road and A513 Rugeley Road additionally cross the Bourne Brook.

2.1.5 There are a number of large water bodies within the area of interest. Blithfield Reservoir, with its maximum capacity of 18200000m^3, sits outside the study area, but plays a significant role in the hydrology of the River Blithe. Within the River Trent floodplain there are two large and significant lakes, formerly gravel extraction pits. These are connected to the course of the Old Trent, which bifurcates around the lakes. This bifurcation is visible on mapping from 1887.

2.1.6 There is an existing Environment Agency gauge at Yoxall on the River Trent, recording both level and flow. The closest gauge upstream of the proposed viaduct is Great Haywood, a level only gauge upstream of the River Trent and

River Sow confluence. Additionally, there is one at Hamstall Ridware on the Blithe recording level only. The River Swarbourn is gauged at Hoar Cross upstream of the model extent.

Figure 1: Schematic of key features within the study area



Hydrological description

2.1.7 The River Trent originates in the Pennines to the north of Stoke on Trent.

2.1.8 The catchment area contributing to the downstream boundary of the hydraulic model is 1229km^2 and is predominantly rural.

2.1.9 The River Trent is gauged at Yoxall, approximately 4km downstream of the proposed River Trent viaduct. This is a flow and level gauge and can therefore be used for defining the hydrology. The gauge has a period of record from 1974 to the present, although the station has changed its recording type on a number of occasions and was relocated in 1976.

2.1.10 Standard annual average rainfall for the catchment at Yoxall gauge is 746mm.

2.1.11 Bourne Brook originates in the Cannock Chase area north of Burntwood and flows in a generally north-east direction.

2.1.12 The catchment area contributing to the downstream boundary of the proposed hydraulic model is 33.0km^2 and is predominantly rural.

2.1.13 Bourne Brook is ungauged along its entire length.

2.1.14 Standard Annual Average Rainfall for the catchment at the proposed Kings Bromley viaduct is 721mm.

Railway alignment

2.1.15 The route of the Proposed Scheme crosses the study area from south-east to north-west, crossing Bourne Brook and Crawley Brook on the proposed Kings Bromley viaduct. The embankment between the two viaducts is the Bourne Embankment. Three kilometres further north, the route crosses the River Trent, Luth Burn and a number of unnamed watercourses on the proposed River Trent viaduct. Further detail on the Proposed Scheme can be found in Maps CT-06-202, CT-06-203 and CT-06-204 in the Volume 2 Map Book.

Flood mechanisms

2.1.16 The River Trent is bounded by defences upstream of the Proposed Scheme crossing location near the B5014 Ridware Road bridges. These defences spread the flood flows and hold water back behind them, while pumps are in place to empty the storage areas behind the defences. On the left bank, the defence is bounded by Bentley Brook on its northern edge. A gap in the defence is present close to this location.

2.1.17 A number of land drainage systems convey flood flows from the River Trent, and these increase the flood extent, particularly at the 0.1% AEP. Luth Burn is shown by the existing Environment Agency flood maps to be a distinct flow path from the River Trent. Luth Burn is a small watercourse conveying flows from its catchment only, with no interaction from the River Trent.

2.1.18 Towards the downstream end of the model extent, the River Swarbourn flows parallel to the River Trent, adjacent to Yoxall gauge. It is possible that during very high flow events the River Swarbourn could break its right bank and locally influence results at Yoxall. Therefore, it has been included in the modelling.

2.1.19 Bourne Brook is situated above its floodplain beneath the Proposed Scheme viaduct, causing peak flood levels to flow over the left bank and down towards the A513 Rugeley Road. This is true upstream of the A515 Lichfield Road, however Bourne Brook returns to a more natural topography downstream of the culvert. Upstream of the Proposed Scheme, the Bourne Brook is perched on the left bank.

2.2 Existing understanding of flood risk

Sources of information

2.2.1 Sources of Environment Agency data were assessed as below:

- Flood Map for Planning (Rivers and Sea)[2]; and
- updated Flood Map for Surface Water (uFMfSW)[3].

2.2.2 The proposed River Trent and Kings Bromley viaducts spans Flood Zones 2 (0.1%AEP) and 3 (1.0%AEP) of the Environment Agency Flood Map for Planning as shown in Figure 2.

2.2.3 A number of flood defences are known to be present as identified on the flood maps, mostly upstream of the proposed River Trent viaduct. These are embankments on both sides of the River Trent, with pumps on their crest to pump from the drainage systems behind them into the River Trent. There is an additional embankment that is listed as a flood defence, along the eastern edge of the Yacht Club/Nursing Home Pool gravel pit to the east of the Proposed Scheme.

2.2.4 The Environment Agency flood maps are believed to be derived by National Generalised Modelling for Bourne Brook.

2.2.5 The Environment Agency flood map for Flood Zone 2 is believed to be derived by National Generalised Modelling for the River Trent.

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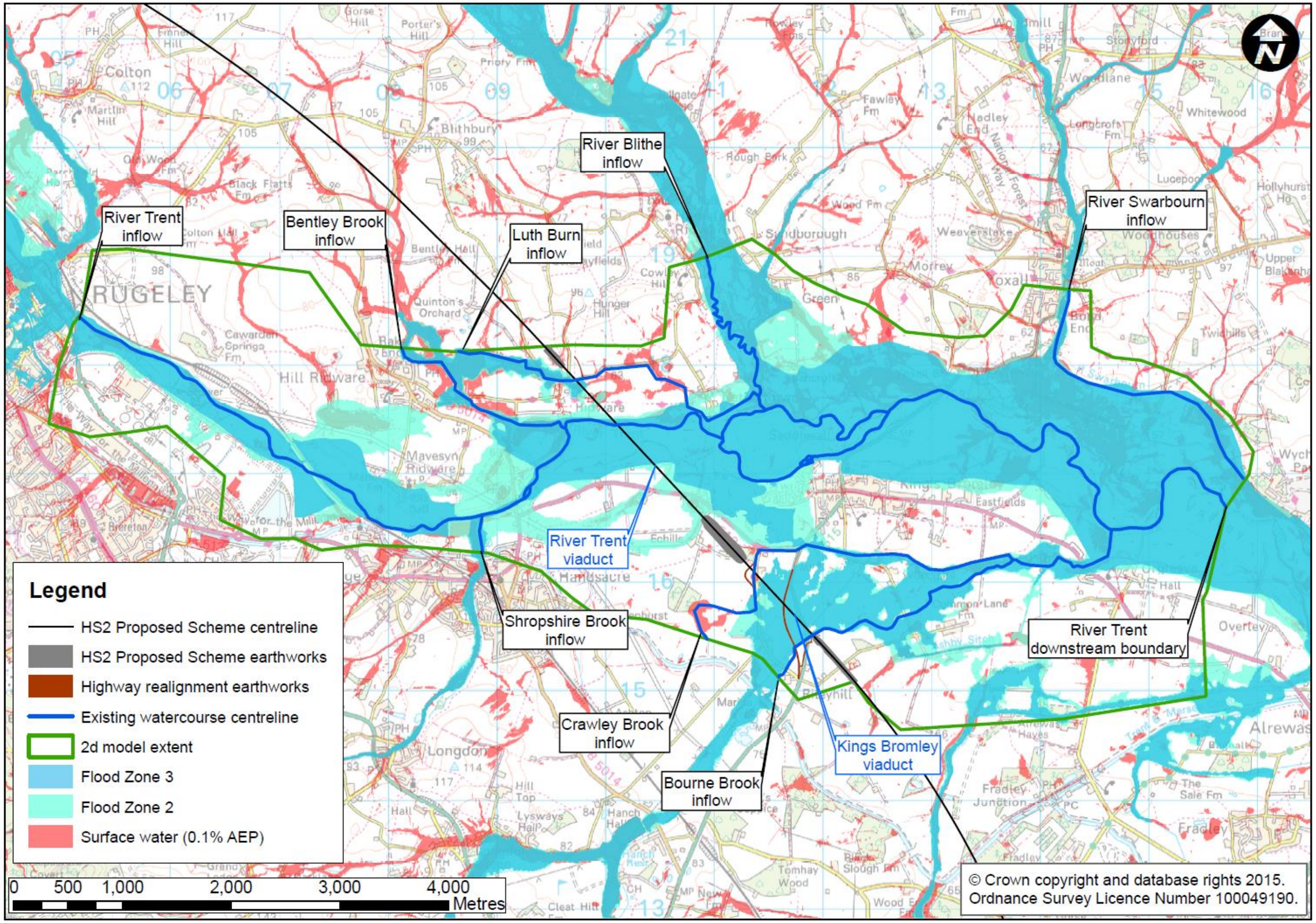
[2] Gov.uk, *Flood map for planning*, https://flood-map-for-planning.service.gov.uk.http://maps.environment-agency.gov.uk/wiyby
[3] Gov.uk, *Long term flood risk information*, https://flood-warning-information.service.gov.uk/long-term-flood-risk/map?map=SurfaceWater

Figure 2: Environment Agency Flood Zones 2 and 3 and uFMfSW (0.1%AEP) at the River Trent at Kings Bromley



2.3 Availability of existing hydraulic models

2.3.1 A number of existing hydraulic models were supplied by the Environment Agency for this study.

2.3.2 The model provided for the River Trent was a 1D only ISIS model received in March 2016. The model was developed in 2004.

2.3.3 The model provided for the River Swarbourn was a 1D-2D (ESTRY- Two-dimensional Unsteady FLOW (TUFLOW)) model received in March 2016. The model was developed in 2007.

2.3.4 The River Trent model was developed on behalf of the Environment Agency for the Trent Strategy. This 1D (ISIS) only model was constructed with peak flood levels then extrapolated across the floodplain to form the flood map. The study area lies within Trent Strategy Model 2, which covers from Darlaston near Stoke, to Drakelow Park near Burton-on-Trent. The maximum return period at which this model was run was the 0.5%AEP event. Therefore, the 0.1%AEP for this area is believed to be derived from National Generalised Modelling. It is unknown if the Flood Zone 3 shown on the Flood Map for Planning is that derived from this model.

2.3.5 The River Swarbourn model was developed on behalf of the Environment Agency. This model forms the basis of the flood map for this watercourse, although this model did not extend to the Swarbourn-Trent confluence, as it was specifically focussed on flood risk within the village of Yoxall itself. This model is within the proposed model extent and has been utilised within the study.

2.3.6 A model built in 2013 for the Environment Agency was also supplied. This covered a reach around Rugeley, focussed on two new bridges on the A51 Rugeley Bypass over the River Trent. However, this is outside of the proposed model extent and has therefore not been utilised.

2.4 Site Visit

2.4.1 A site visit was undertaken in June 2016 to determine the dimensions of the channel and any existing infrastructure.

2.4.2 Several structures were visited; however, not all could be visited due to site access restrictions and general accessibility issues. For the structures that were visited, images were taken to ascertain dimensions and roughness.

2.4.3 Two flood relief culverts were observed beneath the A515 Lichfield Road and then identified on aerial photography, while culverts on Bourne Brook were measured on site.

2.4.4 At Yoxall two bridges were identified next to each other, just upstream of the gauging station. These are shown in Figure 3, taken from the left bank, with the stone arch bridge being the upstream of the two.

2.4.5 Additionally, site visits for WFD purposes in November 2016 provided further information regarding channel capacity.

Figure 3: Yoxall bridges

3 Model approach and justification

3.1 Model conceptualisation

3.1.1 Model extents were carefully selected to ensure that the model boundaries did not have any impact on the flood extent in the area of interest.

3.1.2 Utilising a 1D-2D modelling approach is appropriate for a floodplain of this nature because there are complex overland flow paths between Bourne Brook and the River Trent, and across the floodplain itself beneath the proposed River Trent viaduct. Using such an approach allows more confidence to be gained in assessing the impact of the Proposed Scheme on receptors, while also allowing more confidence in hydrology as floodplain flows can be properly accounted for.

3.1.3 The available models were utilised to inform the basis of the study. The ISIS model which covers the River Trent within the study area was combined with the River Swarbourn model in the 2D element, and the Trent was converted to a 1D-2D Flood Modeller-TUFLOW model, while the Swarbourn ESTRY sections were converted to Flood Modeller.

3.1.4 For those watercourses without an existing 1D model, a 2D only approach was taken due to the lack of data. This approach is suitable as it allows for full representation of the floodplain, while also allowing for a conservative assessment of the channel capacity. Bourne Brook has been modified in the 2D domain to ensure the flow route is represented.

3.1.5 Bourne Brook and the River Trent were modelled together because the gravel pits, particularly the pit to the south of the Trent Yacht Club/Nursing Home Pool, were believed to provide connectivity between the two floodplains. Neither the flood maps nor the hydraulic model, due to its 1D nature, demonstrated how this connectivity occurred.

3.2 Software

3.2.1 Flood Modeller 4.1 has been used for the 1D component of the modelling, including sections on the Swarbourn which were extracted from ESTRY and converted to Flood Modeller. For the 2D component, TUFLOW (2016-AA) has been used. This methodology is in line with standard practice to use the latest available build at the time modelling commenced, while Flood Modeller and TUFLOW are industry standard software.

3.3 Topographic survey

3.3.1 Channel survey for the River Swarbourn was supplied by the Environment Agency. Channel survey for the River Trent exists within the hydraulic model, however the data itself was not supplied and it has therefore not been possible to verify this information. Additionally, the model is not georeferenced so the location of the sections is unknown and has had to be approximated.

3.3.2 No additional topographic survey was commissioned for this study.

3.4 Input data

3.4.1 The Trent Strategy 2 Model (2004) and the River Swarbourn Model (2007) were used as the basis for the hydraulic model developed for this study.

3.4.2 The elevation data for the study area was produced using 200mm Light Detection and Ranging (LiDAR) flown specifically for HS2 Ltd and covers 500m either side of the route centreline. In addition, 1m and 2m LiDAR provided by the Environment Agency and 5m LiDAR provided by DEFRA was used for the remainder of the modelled extent.

3.4.3 The 1D data available as supplied by the Environment Agency was re-schematised as the cross-sections were not georeferenced. Therefore, using bank levels and local structures named within the model as a guide, the sections were repositioned as accurately as possible. This necessitated changes to the node names of all nodes within the hydraulic model, as distances between sections were measured more accurately.

4 Technical method and implementation

4.1 Hydrological assessment

4.1.1 The estimation of design peak flows and hydrographs was based on the application of the methodologies pre-approved by HS2 Ltd. These are standard in the UK flood risk management industry.

4.1.2 The FEH methodologies were followed, in particular the Statistical Methods. The FEH Pooling group uses recorded river flows in hydrologically similar catchments to estimate flows at the subject location. The calculations were based on the most up-to-date national database available at the time of the undertaking the calculations. The data was obtained from the National River Flow Archive and/or HiFlowsUK.

4.1.3 Where available, recorded river flows were used and analysed statistically to obtain estimates of peak flows for a range of event probabilities.

4.1.4 The gauging station at Yoxall was comprehensively analysed to maximise the use of the long flow record length and the outputs of the FEH Single Site analysis were used to estimate peak flows for the River Trent. The area and the interaction of the watercourse are highly complex and there was a notable absence of reliable river gauges which could be relied upon.

4.1.5 In addition, the FEH Revitalised Rainfall Runoff Method, version 2 (part of ReFH2) was used to produce an alternative set of design peak flows and event probability. ReFH2 uses the recently updated FEH13 rainfall database and parameters. The calculations are based on relevant catchment descriptors of each catchment, which were obtained from the FEH Web Service database.

4.1.6 The previous modelling work of the River Trent, carried out in 2004, was consulted and analysed to provide a benchmark for the new flow estimates. All the flow estimates obtained from the various methodologies were analysed and compared, selecting the methodology that produced the most conservative river flows. The adopted river peak flow source varied depending on the watercourse: The River Trent flows were based on the flow records at Yoxall, their flows for the River Blithe and Swarbourn come from ReFH2, whereas for the remaining watercourses, FEH Statistical Method (Pooling Group) provided the design peak flows.

4.1.7 The timing of the hydrological peaks was not chosen to be matched because of the significant difference in catchment sizes. Bourne Brook has a catchment area of $30km^2$, and the River Trent at this point of $1350km^2$ and while they interact, this is not assumed to be significant, however both catchments use the same critical storm duration.

4.1.8 The design hydrographs used for the hydraulic modelling stage were generated using ReFH2 as the FEH Statistical method does not produce time series, just peak flows. The values were scaled so the peak flow for each return period matched that selected as the design value.

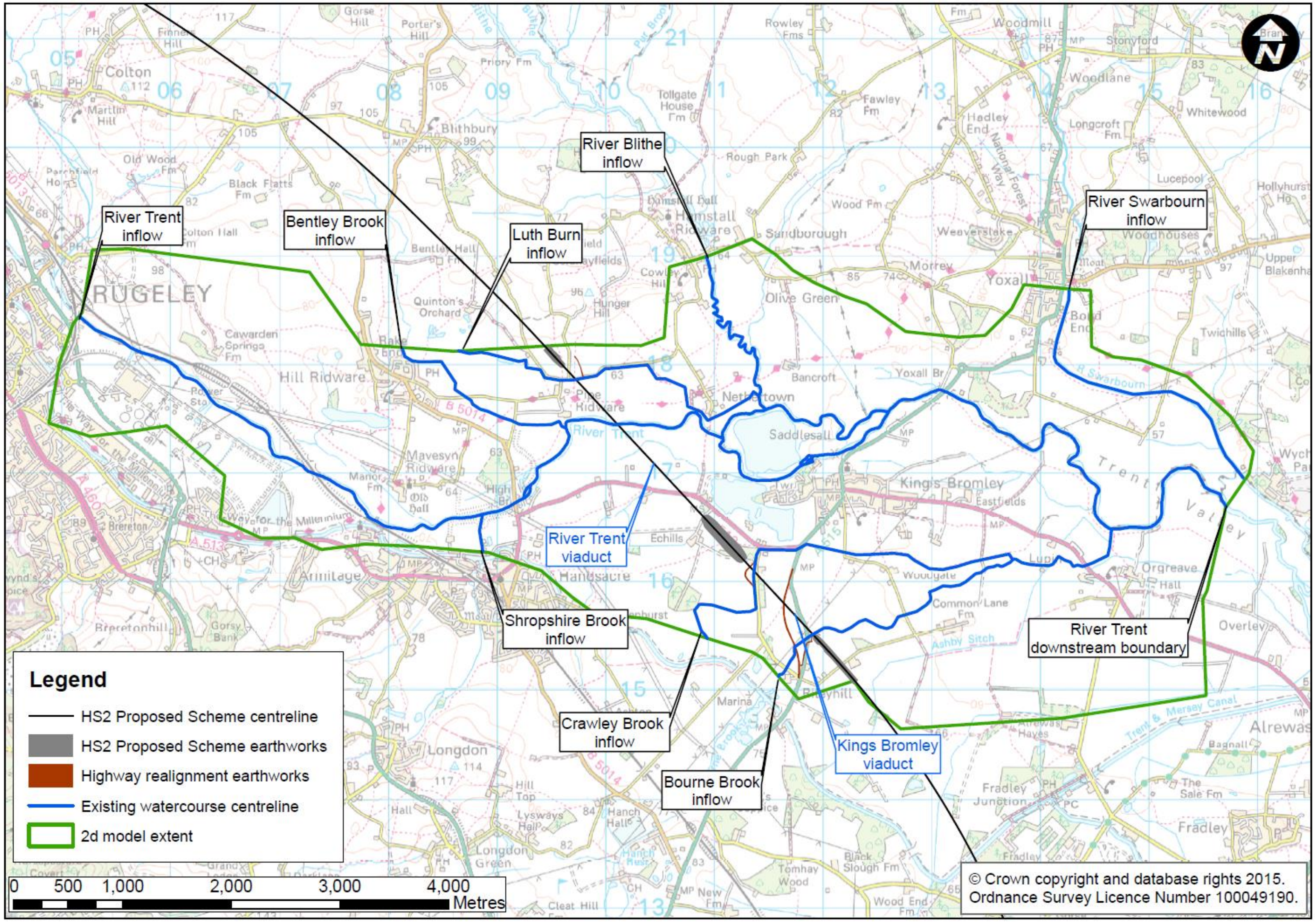
4.1.9 Table 1 shows the peak flows used for the computational hydraulic modelling work. Figure 4 highlights the inflow locations and the associated river networks assessed as part of this study.

Table 1: Peak flows used for hydraulic analysis

	AEP	Return period	Site code									
			River Trent inflow	Shropshire Brook inflow	Lateral inflow 1	Bentley Brook inflow	Luth Burn inflow	River Blyth inflow	Lateral inflow 2	Bourne Brook inflow	Crawley Brook inflow	River Swarbourn inflow
Flood peak (m³/s)	50%	2yr	56.96	1.92	0.20	0.75	0.83	24.72	1.21	3.33	0.36	13.24
	20%	5yr	77.48	2.69	0.27	1.02	1.14	31.67	1.64	4.66	0.50	17.14
	5.0%	20yr	115.07	3.88	0.40	1.45	1.63	42.72	2.44	6.50	0.70	23.64
	1.33%	75yr	168.01	5.32	0.58	1.94	2.22	56.81	3.56	8.47	0.92	32.24
	1.0%	100yr	182.78	5.69	0.63	2.07	2.38	60.56	3.87	8.95	0.98	34.47
	1.0% + CC	100yr + CC	274.17	8.53	0.95	3.10	3.57	90.84	5.81	13.42	1.46	51.71
	0.5%	200yr	224.51	6.67	0.78	2.40	2.79	70.58	4.76	10.17	1.12	40.14
	0.1%	1000yr	367.11	9.59	1.27	3.38	4.05	97.21	7.78	13.49	1.52	54.44

4.1.10 Additional to these inflows were two lateral inflows, to account for areas of catchment between the Trent and Blithe confluences and the Trent and Bourne confluences. These are not shown in Figure 4.

Figure 4: Schematic of inflows and modelled river network



4.2 Hydraulic model build - baseline model

1D Representation

4.2.1 The accuracy of distances between model cross-sections was checked for accuracy, and some sections were relocated, or the stated distance between them increased or decreased. This was based on latest LiDAR information and known positions of structures referenced in the model. All structures that have a deck which is less than three 2D cells wide have had an overspill included in the 1D model. All structures represented in the 1D model are marked with comments stating the location and the source of the data.

4.2.2 Defined flow paths through culverts observed within the 2D domain but not represented within the 1D river channel model have been included as ESTRY components connected using standard methods.

4.2.3 Upstream of the defences on the River Trent, the 1D representation is wider than the channel itself, to prevent model instability due to the defences forming a barrier to flow along the floodplain.

2D Representation

4.2.4 The cell size of the model was set as 6m. Cell size and alignment for the 2D model grid was optimised to ensure appropriate representation of the flow pathways whilst maintaining reasonable run times. The alignment for the 2D model grid follows the rotation of the Proposed Scheme piers. The 1D model was linked to the 2D floodplain.

4.2.5 Bank line heights were sampled from the 2m, 1m and 200mm LiDAR, at whichever resolution was the highest available in each location. These have then been integrated with the 1D bank heights at the cross-section locations.

Inflow boundaries

4.2.6 Inflow boundaries were included within both the 1D and the 2D. The Trent and Swarbourn, both modelled in 1D-2D, were included in the 1D model domain, while the River Blithe, Bourne Brook and a number of very minor tributaries were included in the 2D model domain. These are shown in Figure 4.

4.2.7 The pumps that are known to be present on the crest of the defences by Handsacre were assumed to be working at maximum capacity at all times regardless of whether there was any water behind the defences. This is conservative, but due to the very small capacity of the pumps, this has very little effect. Information on the capacity of the pumps was provided by the Environment Agency, and these have been modelled as fixed inflows rather than explicit pumps.

Downstream boundary

4.2.8 A normal depth boundary was used at the downstream cross-section of the River Trent and also in the floodplain at the downstream extent. This generates a stage-discharge curve based on the bed slope which varies across the floodplain.

4.2.9 A normal depth slope of 0.001m/m (1 in 1000) was used in the 2D domain, and calculated by the hydraulic model in the 1D domain. The normal depth slope was derived from LiDAR.

Key structures

4.2.10 There are a number of structures within the model extent that were modelled in a variety of ways. Additionally, there are a number of structures which are not modelled as no information is available. Those included in the model and deemed to be key hydraulic controls are detailed in Table 2.

Table 2: Key structures present within the modelled extent of Bourne Brook and the River Trent at Kings Bromley

Structure reference	Structure description	Modelling unit and justification
YOX_F_US	Yoxall Multi Arch Footbridge over River Trent 3 arches of varying widths Soffits all 60.25 metres above Ordnance Datum	Arch Bridge – observed on site to be an arch bridge.
FRC1	Flood Relief Culvert beneath A515 Lichfield Road between Yoxall and Kings Bromley 22.0m (L) x 14.0m (W) x 0.85m (H)	1D ESTRY Rectangular culvert – shown to be rectangular from aerial photography
FRC2	Flood Relief Culvert beneath A515 Lichfield Road between Yoxall and Kings Bromley 24.6m (L) x 24.0m (W) x 1.0m (H)	1D ESTRY Rectangular culvert – shown to be rectangular from aerial photography
Bourne2	A515 Lichfield Road crossing of Bourne Brook 12.0m (L) x 6.5m (W) x 1.5m (H)	1D ESTRY Rectangular culvert – Observed on site visit by WFD team

4.2.11 Additionally, a number of other culverts and bridges are included within the hydraulic modelling, however these are not deemed to be critical to determining the flood risk to the Proposed Scheme. This includes, but is not limited to, the B5014 Ridware Road and the WCML over the River Trent and a number of access track culverts on the River Swarbourn.

4.2.12 Omitted structures include, as previously mentioned, high deck bridges at the B5014 Ridware Road crossing and A515 Lichfield Road crossing. These are omitted because they are unlikely to cause an impact to water levels within the channel.

4.2.13 A number of very minor pipe bridges and footbridges on the River Trent upstream of the bifurcation are also omitted.

4.2.14 There are an unknown number of weirs on the edge of Kings Bromley on the Old Trent where the channel is known to split into three. These have been omitted as there was no available data on them.

Roughness

4.2.15 Roughness values utilised are in line with the recommended values stated within Chow, 1959[4].

4.2.16 The 2D domain roughness values have been informed by the land use classifications within the current Ordnance Survey (OS) Mastermap data together with information derived from aerial and site visit photography for specific features.

4.2.17 Manning's 'n' for the channels has been left unchanged for the River Trent as the survey photographs and raw data were not supplied. For the River Swarbourn, minor updates were made to the Manning's 'n' but it was left largely unchanged.

4.3 Hydraulic model build - Proposed Scheme

4.3.1 The Proposed Scheme model has been edited from the baseline to include the following:

Viaduct piers

4.3.2 The proposed Kings Bromley viaduct spans approximately 980m and will be supported by 40 piers, spaced approximately 25m apart.

4.3.3 The proposed River Trent viaduct spans approximately 1.9Km and will be supported by 74 piers, spaced approximately 25m apart.

4.3.4 A deactivated code layer was used to represent the piers. The modelled dimensions of each pier constitute a deactivated area of the model of $36m^2$ per pier, for a pier size of 14.5m x 2m ($29m^2$).

Topographic changes

4.3.5 The Proposed Scheme embankments (Pyford North embankment, Bourne embankment and Pipe Ridware embankment), and the associated realignments of Shaw Lane and the A515 Lichfield Road have been included using the relevant heights for embankment crest and road alignment. The footprints of the embankments for the scheme are based on detail as shown in Maps CT-06-202, CT-06-203 and CT-06-204 in the Volume 2 Map Book.

4.3.6 The Bourne embankment is located in the modelled flood zones for baseline conditions at its southern extent.

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[4] Chow, V.T. (1959), *Open-channel hydraulics*, McGraw-Hill, New York

4.3.7 The OS Mastermap layer was modified to correctly represent any changes to the roughness and planting associated with the Proposed Scheme.

Replacement floodplain storage areas

4.3.8 Although there are only localised changes between baseline and post-development, provision for replacement floodplain storage has been made based on the 1.0% + CC AEP levels, on a level for level, volume for volume basis. This has not been included within the hydraulic modelling for the River Trent. It has been included for the Bourne Brook, close to Shaw Lane as highlighted in the CT-06 maps.

Channel realignment or diversions

4.3.9 Small channel realignments have been made for the Crawley Brook and a drain beneath the proposed River Trent viaduct.

4.3.10 No diversions of the river channel have been proposed.

Production of flood extents

4.3.11 Flood extents have been derived using the direct output options now available in TUFLOW to produce ASCII output for the maximum depth and height. This has then been converted into a polygon, and cleaned to remove all bow ties (where two polygons overlap) as well as any dry islands less than $48m^2$.

Modelling assumptions made

4.3.12 Existing topographic survey is assumed to be correct as no other information is available. This covers all the existing cross-section data for the Rivers Swarbourn and Trent. It is noted that the River Trent survey is up to 21 years old. The survey for the Swarbourn was available to cross-check against, however the survey for the River Trent was not.

4.3.13 Culvert sizes have been assumed in a number of locations within the model. Where a site visit to provide photos or measurements was not possible, they have been approximated based on LiDAR information. This provided road levels and ground levels, and the measured width of the top of structures from aerial photography.

4.3.14 Channel widths have been assumed based on LiDAR and site specific photos at crossing points. Channels have been defined on this basis in a number of locations.

4.4 Climate Change

4.4.1 The climate change allowance for the River Trent and Bourne Brook is 50% based on the new climate change approach developed by the Environment Agency and published in February 2016.[5]

4.4.2 This climate change percentage considers the design life of the Proposed Scheme (120 years), the River Basin District (Humber) and the receptors within the existing Flood Map for Planning. Due to the presence of more vulnerable receptors (National Planning Policy Framework Table 2[6]), the upper end value for the longest duration was chosen.

4.4.3 The new climate change guidance recommends consideration of the H++ scenario[7]. While these percentages have not been explicitly assessed, the sensitivity for the 20% increase in flow on the 1.0% + CC AEP event is assumed to be representative of an event greater than the H++ scenario.

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[5] Environment Agency, *Flood risk assessments: climate change allowances*, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances
[6] Gov.uk, *Flood Zone and flood risk tables,* https://www.gov.uk/guidance/flood-risk-and-coastal-change#flood-zone-and-flood-risk-tables
[7] Environment Agency, *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/571572/LIT_5707.pdf

5 Model results

5.1.1 The model has been run for the 50%, 20%, 5.0%, 1.33%, 1.0%, 1.0%+CC, 0.5% and 0.1% AEPs. The 1.0% +CC simulation is based on a 50% increase in flows.

5.1.2 The water level difference has been mapped for the 1.0%+CC and 5.0% AEPs. These flood maps are reported in Appendix A.

5.1.3 In all return periods modelled apart from the 50% AEP, impacts are observed around the realigned A515 Lichfield Road beneath the proposed Kings Bromley viaduct of greater than 100mm. A change to the flood extent is observed due to the provision of replacement floodplain storage for the proposed Kings Bromley viaduct.

5.1.4 More generally across the River Trent and Bourne Brook catchments, impacts of up to 10mm are observed.

5.1.5 In the 5.0% AEP results, an impact is observed at the north abutment of the proposed River Trent viaduct by the village of Pipe Ridware of in excess of 100mm. This is believed to be due to limitations regarding resolution of the model grid.

5.1.6 Additional impacts are observed in the 5.0%AEP event upstream of the WCML, approximately 3.5km upstream of the proposed Scheme, which are also believed to be due to model resolution causing a different number of iterations to be applied to the model, resulting in differing levels.

5.1.7 In a 1.0% + CC AEP event there are increases up to 100mm behind defences north and south of the Trent at Handsacre. These are believed to be caused by a different number of iterations forcing a slightly greater amount of water through a small gap in the defences on the north side, and round the embankment toe to the south. This impact is not observed in any other AEP event.

5.1.8 Model results conclude that the current proposed design ensures a freeboard of a minimum of 1m to the rail track in a 0.1%AEP event and a minimum of 0.6m to the viaduct soffit in a 1.0%AEP + CC (50%) event for all scenarios.

6 Model proving

6.1 Introduction

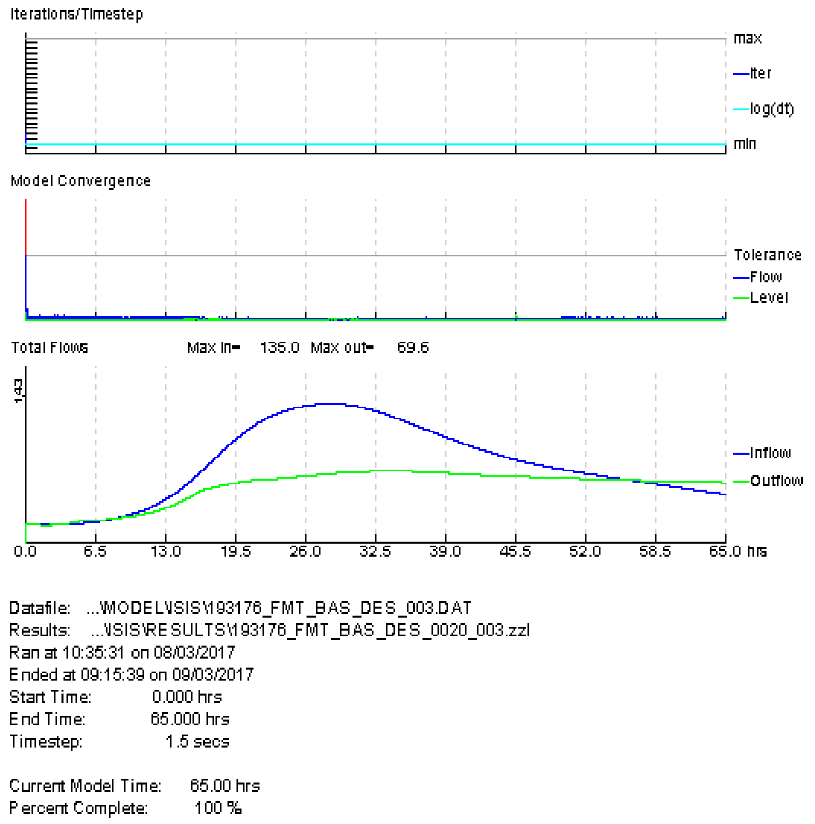
6.1.1 This section of the report presents the analysis of the model undertaken to ensure confidence in the stability of the model build, its response to input values and consistency with previous modelling.

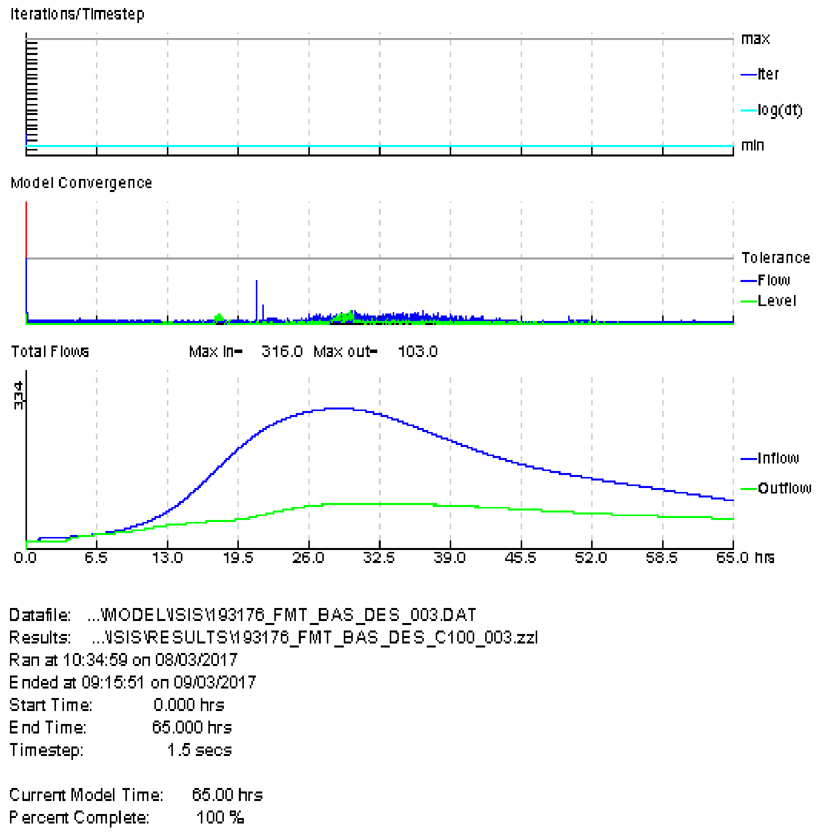
6.2 Run performance

6.2.1 Model outputs have been reviewed across all open channel and model structures to assess model stability and overall model performance.

6.2.2 In all events the model shows fully convergent simulations. Figure 5 shows the convergence plots for the Proposed Scheme 5.0% and 0.1% AEP simulations.

Figure 5: Model convergence plot for the 5.0%AEP (top) and 1.0%+CC AEP (bottom) simulations on the HS2 Proposed Scheme model





6.2.3 Final cumulative mass balance error is within +/-1.0% for all return periods and blockage and sensitivity cases simulated. However, there are negative depths in 0.1%AEP events, which are associated with an area local to Rugeley Power Station at the upstream end of the model and as such do not have an impact on results at the Proposed Scheme.

6.2.4 However it was noted that a different number of iterations were used when the scheme was included within the hydraulic model, thus causing a slight impact to be observed.

6.3 Calibration and validation

6.3.1 Yoxall level and flow gauge is within a suitable distance to provide calibration data for the model. However, calibration has not been carried out due to the lack of historic flood mapping and recorded flooding information, while the available rainfall information is spatially variable. Additionally, there is no historic information regarding the water level of the gravel pits during flood events and this has been documented as a calibration issue in previous modelling studies in this area.

6.4 Verification

6.4.1 Model outputs have been compared with other readily available flood risk data such as Environment Agency Flood Maps for Planning.

6.4.2 Flood extents generated for this study generally show that there is a decrease in flood extent when compared to the Environment Agency Flood Map for Planning at a 1.0%AEP event. However, at the 0.1%AEP event, the extents are broadly similar.

6.4.3 For Bourne Brook, the farmland downstream of the A515 Lichfield Road shown as being within the flood zones of the Environment Agency Flood Map for Planning, is not shown as flooded by this study for all AEP.

6.5 Sensitivity analysis

6.5.1 Sensitivity scenarios were undertaken as below:

- increase in flow by 20% (compared to 1.0%AEP+CC Proposed Scheme);
- increase in roughness (channel, structures and floodplain) (Manning's n) by 20% (compared to 1.0%AEP+CC Proposed Scheme);
- decrease in roughness (channel, structures and floodplain) (Manning's n) by 20% (compared to 1.0%AEP+CC Proposed Scheme);
- increase in downstream boundary gradient by 20% (compared to 1.0%AEP+CC Proposed Scheme); and
- decrease in downstream boundary gradient by 20% (compared to 1.0%AEP+CC Proposed Scheme).

Roughness

6.5.2 The model is sensitive to increases in roughness with a 20% increase resulting in increases in water level of varying degrees ranging from 10mm to 100mm throughout the model. The effect of increase has greatest impact upstream of the Proposed Scheme near the flood defences, which act as a throttle on the floodplain, and at the downstream end of the model. However, there are also impacts of over 100mm observed at the proposed River Trent viaduct. There is very little impact observed on Bourne Brook, with the maximum increases being around 50mm at the proposed Kings Bromley viaduct.

6.5.3 Additionally, increased roughness activates a flow path observed in a 0.1% AEP event. This flow path is to the south of the River Trent. Due to this, increased roughness has been taken forward as the design flood extent to inform the viaduct length. This is shown in Appendix A, Figure A1-3.

6.5.4 Decreasing the roughness by 20% results in a general decrease in peak water level throughout the model of approximately 100mm.

Inflows

6.5.5 An increase in inflow of 20% results in a maximum increase of greater than 100mm at the proposed River Trent viaduct. An increase in flood extent is observed as described above regarding 20% increases in roughness.

Downstream boundary

6.5.6 There was no impact to the Proposed Scheme crossing when the downstream boundary was reduced and increased by 20%, with impacts greater than 100mm at the downstream boundary. No impact is seen greater than 1.9km from the downstream extent.

Summary

6.5.7 The sensitivity analysis shows the model is sensitive to changes in flows and very sensitive to changes in roughness values at the Proposed Scheme crossing locations. The changes in the downstream boundary gradient had no impact at the Proposed Scheme crossing with minimal impact at the downstream boundary of the model.

6.5.8 Increased roughness impacts on flood extents means that this sensitivity test result has been taken forward as the design flood extent to inform the viaduct length.

6.5.9 Sensitivity tests conclude that the current proposed design ensures a freeboard of a minimum of 0.6m to the viaduct soffit in a 1.0%AEP +CC (50%) event for all scenarios.

6.6 Blockage analysis

6.6.1 Two blockage scenarios were assessed:

- blockage scenario 1 – 2.0% blockage at the proposed Kings Bromley and River Trent viaducts; and
- blockage scenario 2 – 50% blockage of the flood relief culverts beneath A515 Lichfield Road and Yoxall Arch Bridge.

6.6.2 These blockage scenario results were compared to the 0.1% AEP results for the Proposed Scheme model.

6.6.3 The viaduct blockage of 2.0% was represented for the proposed Kings Bromley and River Trent viaducts by expanding the size of the pier standing nearest to the main channel by 2% of the length of the viaduct.

6.6.4 The blockage of the flood relief culverts beneath A515 Lichfield Road and Yoxall Arch Bridge was represented by use of a blockage unit for the bridge, and through reducing the width of the culverts by 50%.

6.6.5 The results for blockage scenario 1 show negligible impact to flood levels and extents of up to 10mm generally around the north abutment of the proposed Kings Bromley viaduct and around the centre of the River Trent viaduct.

6.6.6 The results for blockage scenario 2 indicate that local to the blockage at Yoxall, significant impacts of greater than 100mm are observed. However, this causes no impact at the River Trent viaduct and up to 10mm at the proposed Kings Bromley viaduct, with localised patches up to 50mm.

6.6.7 Blockage tests conclude that the current proposed design ensures a freeboard of a minimum of 1m to the rail track in a 0.1%AEP event for all scenarios.

6.7 Run parameters

6.7.1 Maximum iterations have been increased from 11 to 23 within the Flood Modeller element.

6.7.2 The time step parameters used were 1.5 seconds for the 1D model river, 0.5 seconds for ESTRY and 3 seconds for the 2D model. This is the suggested approach for a grid size of 6m.

7 Limitations

7.1.1 Land access for new topographic survey was not possible, and therefore the existing survey within the Environment Agency hydraulic models and Environment Agency provided raw survey data for the Swarbourn is believed to be correct. 5m LiDAR is the only available data in one location on the Bourne Brook, and this may under or overestimate the capacity of the floodplain. Some culvert dimensions have been estimated based upon ground levels and watercourse size, which may impact flood extent and level predictions if these were to change.

7.1.2 No survey data was available for the other watercourses and therefore, for these, the model has been developed based on the LiDAR provided.

7.1.3 No survey data was available for a number of structures on the River Trent by King's Bromley.

7.1.4 The 6m grid size was chosen so that run times were not excessive. However, this means small flow paths and watercourses, such as Crawley Brook, Luth Burn and a number of drains are not adequately represented, while Bourne Brook is represented as a channel which is slightly too wide. This is believed to be the cause of some of the significant effects observed upstream of the WCML.

7.1.5 At the Shropshire Brook, upstream of the Proposed Scheme, there may be an outfall for the brook into the River Trent. However, this has not been confirmed. The impact that this would have on the floodplain is unknown at this stage.

7.1.6 LiDAR of the embankment crest north and south of the Trent at Handsacre appears to be inaccurate. Due to varying embankment levels indicated by LiDAR in this location flood level impacts are observed in 1%AEP+CC event that may be inaccurate.

7.1.7 Calibration has not been able to be carried out due to a lack of available data.

8 Conclusions and recommendations

8.1.1 The aim of developing a hydraulic model of Bourne Brook and the River Trent to simulate the baseline and Proposed Scheme; to determine the peak water levels and flows throughout the catchment has been met.

8.1.2 Increases in water level are observed due to the Proposed Scheme, up to 200mm in a 1.0% +CC AEP event, close to Pipe Ridware, although as discussed this is most likely due to limitations with the model. More generally, there is negligible impact in all return periods.

8.1.3 Blockage and sensitivity analyses have demonstrated that changes in key variables such as roughness, model inflows and downstream boundary location and gradient result in modelled water levels that remain below the critical freeboard requirements.

8.1.4 It is recommended for future modelling to consider obtaining verification of the topographic survey due to the age of the existing information. This specifically includes locations such as the embankment crest north and south of the Trent at Handsacre, and the embankment by the gravel pit to the south of the River Trent at Kings Bromley. Additionally this survey will cover all omitted structures from the modelling around Kings Bromley as previously highlighted.

8.1.5 Further work could look at the grid resolution of the modelling undertaken to date to understand the limitations around this.

8.1.6 It is also recommended that calibration of the model is undertaken following further analysis of the available data.

8.1.7 Carrying out calibration may reduce the significant uncertainty regarding the roughness of the model domain, as increases in roughness have been shown to activate additional flow paths.

8.1.8 It is recommended that analysis of the critical storm durations applied to the hydrology is carried out.

9 References

Chow, V.T (1959), *Open-channel hydraulics*, McGraw-Hill, New York.

Environment Agency, *Flood risk assessments: climate change allowances*. Available online at: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances.

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Appendix A: Flood level impact maps

1.1.1 The water level difference has been mapped for 5.0% AEP and 1.0%+CC AEP as described in Section 5 (Main Report). These are shown in Figure A-1 and Figure A-2

1.1.2 Additionally, Figure A-3 shows the roughness in flow path observed in a 0.1% AEP event.

Figure A-1: Bourne Brook and River Trent Impact Map for 5% AEP (1 in 20 year)

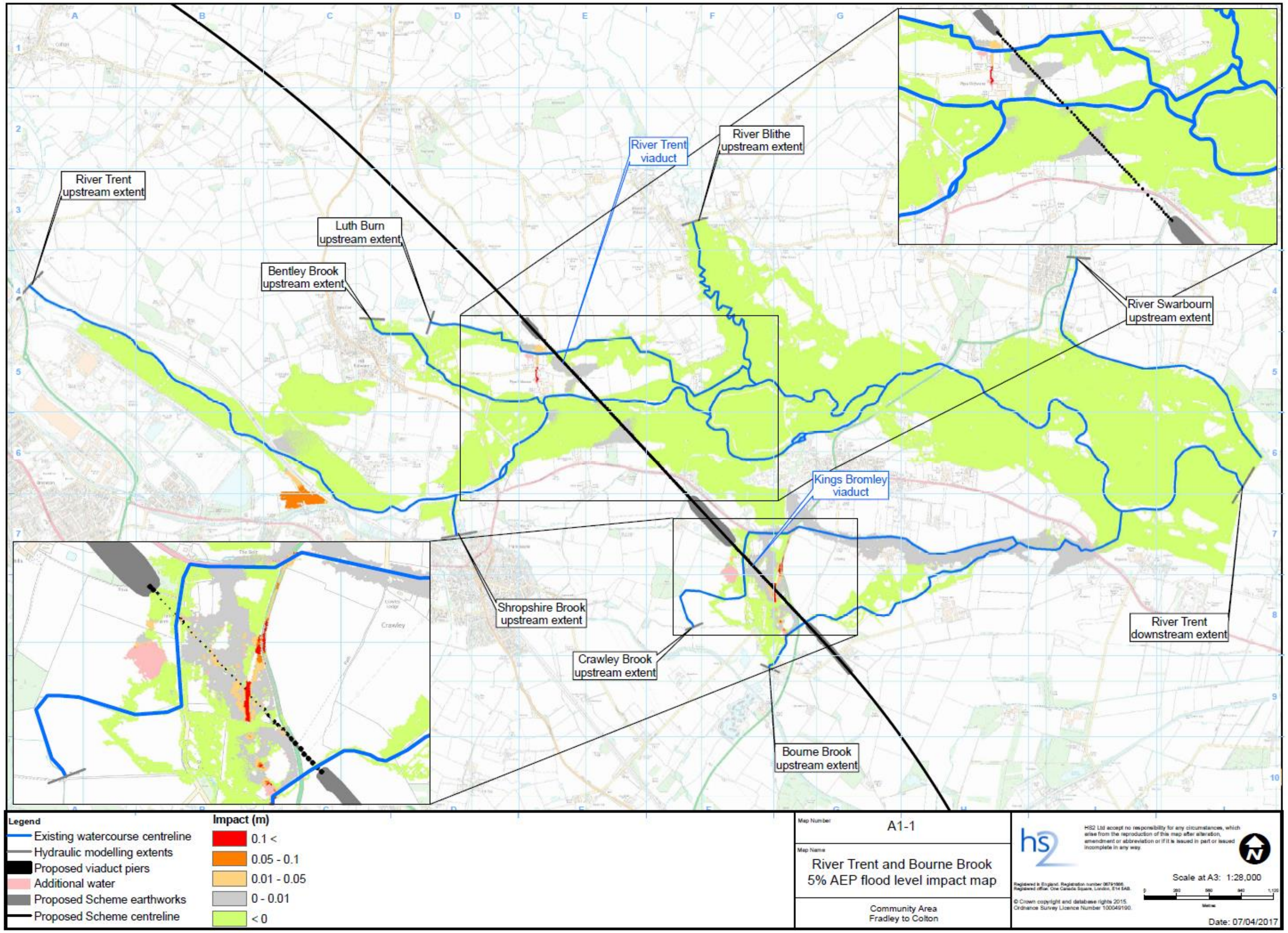


Figure A-2: Bourne Brook and River Trent Impact Map for 1% AEP + CC (1 in 100 year) plus 50% climate change allowance

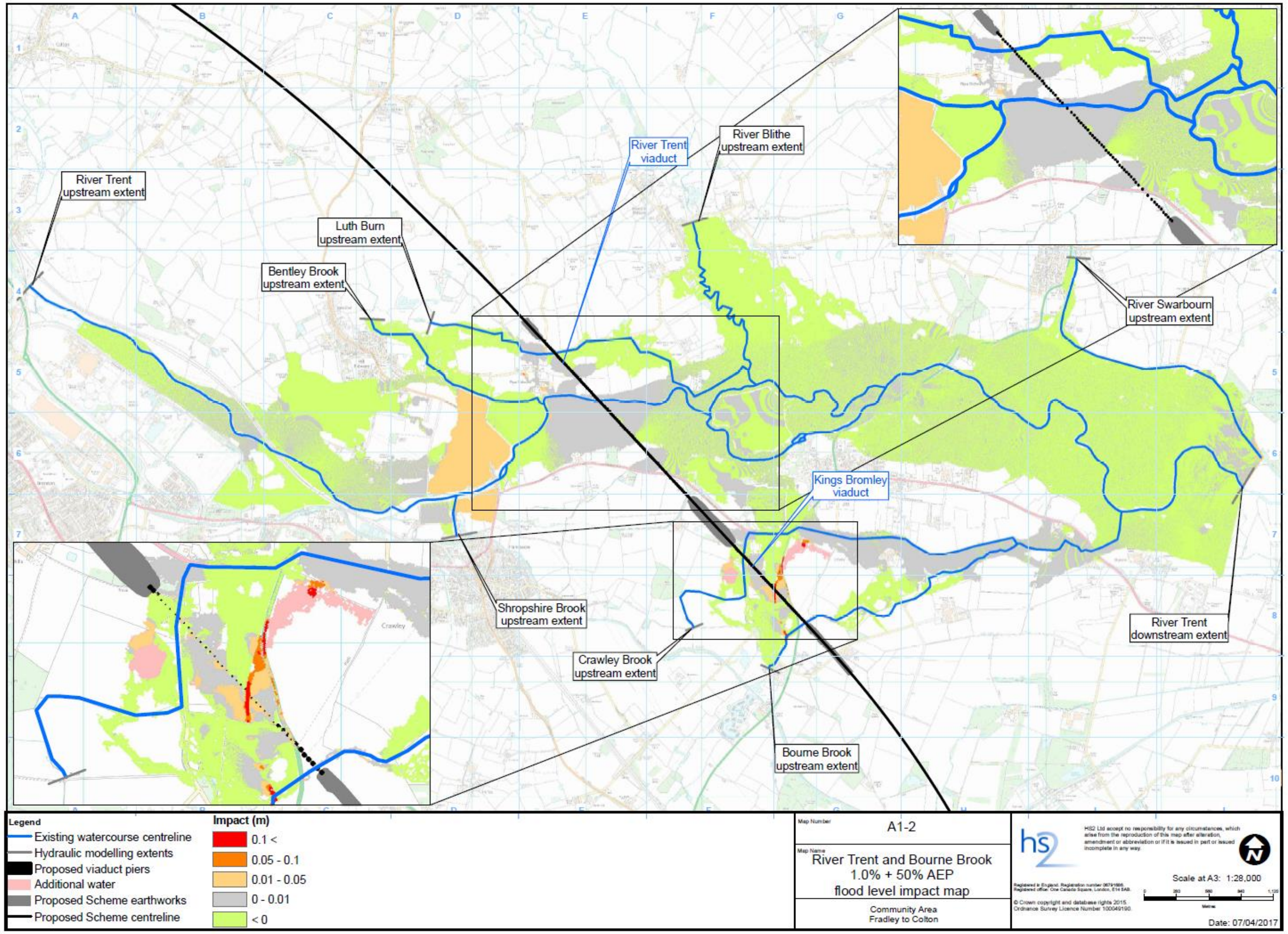
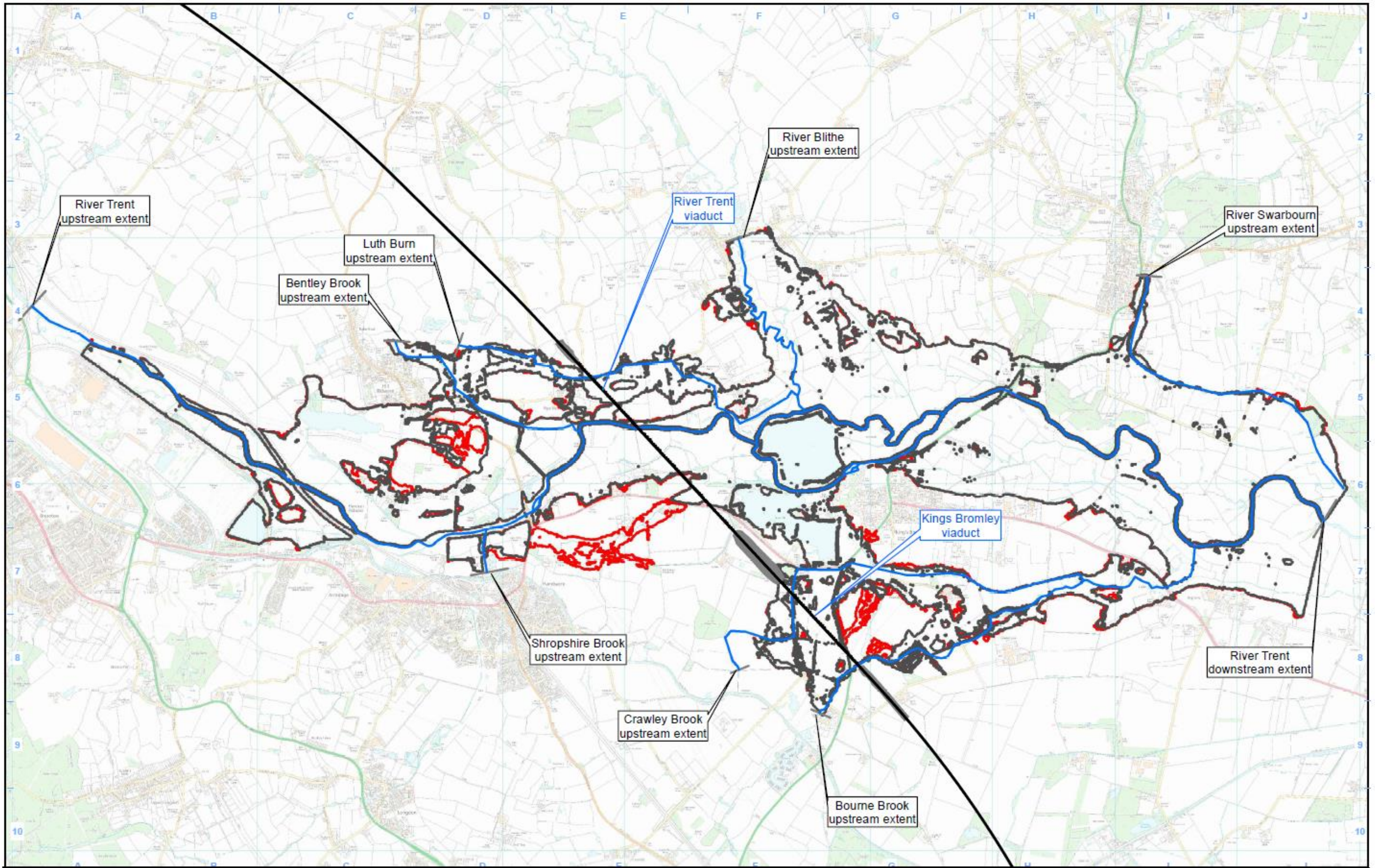


Figure A-3: Bourne Brook and River Trent Impact Map for comparison between 1% AEP + CC (1 in 100 year) plus 50% climate change allowance and roughness + 20%



Legend

- Existing watercourse centreline
- Hydraulic modelling extents
- Proposed Scheme earthworks
- Proposed viaduct piers
- 1% + CC AEP flood outline
- Roughness + 20% flood outline
- Proposed Scheme centreline

Map Number: A1-3

Map Name: River Trent and Bourne Brook comparison of 1.0% + CC AEP and roughness + 20% flood extents

Community Area 1
Fradley to Colton

Scale at A3: 1:28,102

Date: 19/04/2017

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